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# APPLICATION

# FOR

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TITLE: MANUFACTURABLE CHROMELESS ALTERNATING PHASE SHIFT MASK STRUCTURE WITH PHASE GRATING

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# MANUFACTURABLE CHROMELESS ALTERNATING PHASE SHIFT MASK STRUCTURE WITH PHASE GRATING

## BACKGROUND

[0001] A binary photomask may include glass and chrome features which form a pattern. Light may pass through the clear glass areas and be blocked by the opaque chrome areas. Light that passes through the mask may continue through a lens, which projects an image of the mask pattern onto a wafer. The wafer is coated with a photosensitive film (photoresist), which undergoes a chemical reaction when exposed to light. After exposure, the areas on the photoresist exposed to the light may be removed in a developing process, leaving the unexposed areas as features on the wafer.

[0002] The quality of an imaged mask pattern produced with a typical binary mask may be degraded by light from clear areas on the mask diffracting into regions that ideally would be completely dark. The nominally dark region may have light diffracted into it from the adjacent nominally bright regions, thereby affecting the photoresist and quality of the printed pattern. An alternating phase shift mask (APSM) may be used to reduce such diffraction. In the APSM, alternating clear regions (which may be

designated as zero (0) and pi (π) regions) may have different step heights which cause the light to be phase-shifted 180° between the two regions. As a consequence, the light diffracted into the nominally dark area from the clear zero region will interfere destructively with the light diffracted from the adjacent pi region. This may improve image contrast on the wafer.

[0003] An APSM may be fabricated by patterning all features (apertures) in the chrome layer on the quartz mask substrate in a first (binary) step. After the binary processing, the mask is recoated with resist, and the apertures that are to be quartz etched are then exposed. The open apertures are then etched to a 180° phase depth and "converted" to pi apertures. An isotropic etch step may be used to "hide" the phase edge under the chrome. The requirements for this second patterning step are relatively loose, since the chrome region between the zero and pi apertures on which the resist edges must land, which may be relatively large, e.g., about 200 nm for a 193 nm lithography system.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Figure 1 shows an optical lithography system.

[0005] Figure 2 is a side view of an exemplary (alternating phase shift mask) APSM in an imaging system.

[0006] Figure 3 is a plan view of an APSM structure including alternating phase-shifted apertures located in a chrome field.

[0007] Figures 4A to 4D show stages in an APSM fabrication process.

[0008] Figure 5A is a plan view of an exemplary chromeless APSM structure.

[0009] Figure 5B is a sectional view of the exemplary chromeless APSM structure.

[0010] Figure 6 is a flowchart describing a method for fabricating a chromeless APSM contact design.

[0011] Figures 7A to 7C show stages in an APSM fabrication process.

[0012] Figure 8A shows an upper limit of a maximum CD (critical dimension)/overlay.

[0013] Figure 8B shows a lower limit of a maximum CD/overlay.

[0014] Figure 9A shows a simulated aerial view of contacts imaged with a chromeless APSM structure.

[0015] Figure 9B shows the chromeless APSM structure used to image the contacts in Figure 9A.

[0016] Figure 10 shows contrast achieved on the imagery plane using an APSM structure.

## DETAILED DESCRIPTION

[0017] Figure 1 shows an optical lithography system 100. Light from an illumination source 105 is transferred to a patterned mask (or reticle) 110 by an illumination system 115. Light passes through the mask and into the entrance pupil of an imaging system 120. The resulting pattern is imaged onto a photoresist covered wafer 125 by a lens 130 in the imaging system.

[0018] The mask 110 may be an alternating phase shift mask (APSM). The quality of an imaged pattern produced with a typical binary mask may be degraded by light from clear areas on the mask diffracting into regions that ideally would be completely dark. The nominally dark region may have light diffracted into it from the adjacent nominally bright regions. An APSM may be used to reduce such diffraction.

[0019] Figure 2 shows an exemplary APSM 200. In the APSM, alternating clear regions (which may be designated as zero (0) regions 210 and pi (π) regions 205) may have

different step heights which cause the light to be phase-shifted 180°. As a consequence, the light diffracted into the nominally dark area 215 (covered by chrome) from the clear zero region 210 will interfere destructively with the light diffracted from the adjacent pi region 205. This may improve image contrast on the wafer.

**[0020]** Figure 3 shows an APSM structure 300 including six alternating phase-shifted apertures 302, 304 located in a chrome field. The apertures may be used to print six corresponding contacts on a wafer. The structure 300 may include primary zero apertures 302 and primary pi apertures 304 separated by chrome lines 306. The primary apertures may be surrounded by a SRAF (sub-resolution assist feature) zero apertures 308 and SRAF pi apertures 310. The SRAF apertures are additional small features, typically added to the photomask by some simple width and spacing rules, which do not themselves print on the wafer, but may allow isolated or semi-isolated lines to diffract light like dense lines.

**[0021]** The APSM structure 300 may be fabricated by patterning all features (apertures) 402 in the chrome layer 404 on the quartz mask substrate in a first (binary) step, as shown in Figure 4A. This first patterning step may utilize a high precision tool, such as a 50 keV electron

beam lithography tool, to print the apertures on the photoresist on the chrome layer. After the binary processing, the mask is recoated with resist 406, and the apertures 408 that are to be quartz etched are then exposed in a second mask patterning step, as shown in Figure 4B. The open apertures 404 are then etched to 180° phase depth and "converted" to pi apertures. The apertures under the resist remain zero apertures. The resist 406 may then be removed. An isotropic etch step may be used to "hide" the phase edge 410 under the chrome 404, as shown in Figure 4C.

**[0022]** The requirements for the second mask patterning step (Figure 4B) may be relatively loose, since the resist edges must land on top of the chrome 412 between the zero and pi apertures, which may be relatively large, e.g., about 200 nm for a 193 nm lithography system. Since the requirements are more relaxed for the second patterning step, a less precise, and less expensive, tool may be used, such as a laser writer.

**[0023]** "Pitch" refers to the center-to-center distance between features in a pattern. It may be desirable to reduce the pitch between the features on the mask to pack more features into the imaged pattern. However, the pitch may be limited by the resolution of the system (e.g., 193 nm) and the ability to decrease the size of the chrome

lines between apertures, which may depend on the precision of the lithography tool used to print the apertures. For example, reducing the size of the chrome line on a mask from 200 nm (as described above) to 50 nm or less may not be feasible, even with a very precise lithography tool, such as a 50 keV electron beam lithography tool.

**[0024]** In an embodiment, a chromeless APSM structure may be used to enable the pitch of features on the mask to be decreased by removing the chrome line between features, and thus remove the limit based on the size of the chrome line. A chrome line may be provided in a conventional APSM to make an easy place to land resist edges between the zero and pi apertures for the second mask patterning step. However, the chrome line may not be essential for printing adjacent contacts using adjacent phase-shifted apertures in the mask structure. A line separating the adjacent contacts may be produced in the image due to destructive interference between adjacent the light diffracted from the adjacent phase-shifted apertures.

**[0025]** Figures 5A and 5B show a plan view and a sectional view, respectively, of an exemplary chromeless APSM structure 500. This structure may be used to print ten tightly packed contacts. Adjacent primary zero apertures 502 and primary pi apertures 504 may be used to

image the contacts. The primary apertures may be surrounded by a boundary region including an alternating pattern of SRAF zero apertures 506 and SRAF pi apertures 508, which together form a phase grating. The structure may be surrounded by chrome 510. As well as providing sub-resolution assist effects, the SRAF apertures may provide a space buffer for the photoresist in the second mask patterning step in order to allow for relaxed patterning constraints.

**[0026]** Figure 6 is a flowchart describing a method 600 for fabricating a chromeless APSM contact design according to an embodiment. Only the pi features are patterned in the first mask patterning step (block 602), as shown in Figure 7A. After patterning and binary level processing (block 604), the exposed quartz is etched to 180° phase depth (block 606). The quartz etch may be done with either a hard-mask etch (no resist) or with the first level resist patterning still present. If the hard-mask etch path is chosen, the risk of quartz bump defects risk may be minimized by multiple clean/etch cycles. After etching the mask to 180° phase depth, a second mask patterning step is performed (block 608), as shown in Figure 7B. The exposed chrome is removed during an etch process (block 610), and

the area under this removed chrome becomes the zero aperture features as shown in Figure 5A.

[0027] The requirements for the second mask lithographic step may be relatively loose, e.g., similar to the requirements of the mask fabrication process described in Figures 4A-4C. The relaxed constraints of the second mask patterning step may be facilitated by the phase grating surrounding the printable contacts. Figure 5A shows the target for the phase edge, e.g., the middle 520 of the outer row of the phase grating. Figure 8A shows the upper limit of the maximum CD (critical dimension)/overlay, while Figure 8B shows the lower limit of CD/overlay. If more chrome is removed than shown in Figure 8A, then quartz which doesn't have a phase grating may be exposed and could cause printing defects if the exposed area is too large. If less chrome is removed than shown in Figure 8B, then the pi apertures may not be counterbalanced by the zero apertures and could cause printing defects if the exposed area is too large.

[0028] In an embodiment, the second mask patterning step may be optional. If the entire mask utilizes a phase grating then the chrome may be removed from the entire mask, forming a completely chromeless mask.

**[0029]** Figure 9A shows a simulated aerial view of contacts 902 imaged with a chromeless APSM structure with a phase grating field 904 (Figure 9B) in an imaging system with 193 nm wavelength illumination, 0.92 NA and 0.4 Sigma. Figure 10 shows that the chromeless APSM structure provides good contrast.

**[0030]** Although chromeless APSMs with phase grating fields including five SRAF structures have been described, other numbers of SRAF structure may be used, e.g., two, three, four, or six.

**[0031]** A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, blocks in the flowcharts may be skipped or performed out of order and still produce desirable results. Accordingly, other embodiments are within the scope of the following claims.